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A MILP for Green Scheduling Integrating Human Factors

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1 Introduction

The Flexible Job Shop Scheduling Problem (FJSSP) has been widely studied in last decades. The emergence of technological advancements in the context of Industry 4.0 has brought many changes and made production scheduling more and more efficient. Today’s Industry 5.0 paradigm pays great attention to human factors and environmental considerations to enhance the system’s sustainability and resilience [3]. Since 2013, around 100 FJSSP articles have focused on environmental factors like energy consumption. Among these papers, only 13 consider human factors. However, recent literature has shown that the workers’ well-being and skills affect considerably the scheduling performance [2]. FJSSP can be static or dynamic. Dynamic scheduling differs from static scheduling in its ability to react to hazards or disturbances. Solving the dynamic FJSSP should improve the production system’s efficiency and resilience but increase the complexity of the problem regarding its solving. Figures 1 and 2 prove the lack of studies integrating both factors simultaneously, particularly in the dynamic approach. Aiming to increase the production systems’ sustainability and resilience, we propose a MILP to model the human-based green FJSSP.

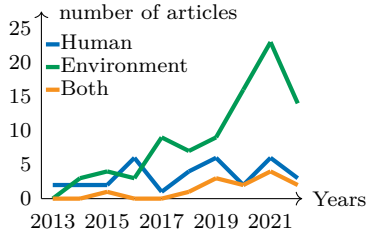


FIG. 1 – Distribution of the surveyed articles

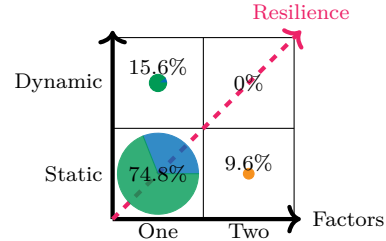


FIG. 2 – Classification of the surveyed articles

2 Proposed model

We propose a FJSSP model taking into account economic, environmental, and human aspects. The principal assumptions of the model are : i) each operation needs one operator and one machine to be processed, ii) machines and operators can perform one operation at a time, iii) an operator rests *REST* of his working time after each operation, and iv) the time horizon is composed of two 7-hour shifts per day. The objective function minimizes the total energy consumption as follows :

$$\min_{\mathbf{X}} EM(\mathbf{X}) + ET(\mathbf{X}) + EC(\mathbf{X}) \quad (1)$$

where \mathbf{X} is a multidimensional vector of binary decision variables defining the schedule, $EM(\mathbf{X})$ the total energy consumption for processing operations on machines, $ET(\mathbf{X})$ the total energy consumption associated to the transport of products between machines, and $EC(\mathbf{X})$ the auxiliary energy consumption, such as lighting or heating, directly linked to the makespan. For human consideration, we use the OCRA index, which predicts the risk of work-related musculoskeletal disorders associated with a given schedule of tasks performed by an operator. In our

model, jobs, tasks, workers, machines, and periods are respectively denoted by $j, k, w, i,$ and t . The decision variable X_{kjwit} indicates if the k -th operation of job j is assigned to worker w and machine i in period t . We defined other intermediary decision variables, which are linear functions of \mathbf{X} : \mathbf{R} for rest time, \mathbf{OCRA} for OCRA index, \mathbf{V} for the assignment of workers on periods, \mathbf{S} and \mathbf{C} for starting and completion times of operations, \mathbf{Y} for the assignment of operations to the same worker, and \mathbf{N} for the assignment of operations on machines. The parameters of the model are : p for the processing time, tv for the travel time, tp for the transport time, s for the the setup time, b and f for, respectively, the beginning and the ending of a period, and d for the due dates. In addition to classical FJSSP constraints, we have the following additional workers-related constraints :

- OCRA index threshold :
$$OCRA_{wt} \leq OCRA^{max} \quad \forall w, t \quad (2)$$

- Rest time for workers :
$$R_{kjwt} = REST \times \sum_i X_{kjwit} \times p_{kji} \quad \forall t, w, j, k \quad (3)$$

- Assignment of workers to periods :
$$V_{tw} + V_{(t+1)w} = 1 \quad \forall t, w \quad (4)$$

- Worker-related precedence constraints :
$$S_{k'j'} + (1 - \sum_w Y_{k'jwk'j'})M \geq C_{kj} + \sum_{w,i,t} R_{kjwt} + \sum_{i,i'} tv_{ii'} \times N_{k'jik'j'i'} \quad \forall j, j', k, k' \quad (5)$$

Figure 3 shows the first results of our model on a small instance, inspired by [1] and completed with information for workers and energy consumption. The instance is composed of 5 machines, 3 workers, and 4 jobs composed of a total of 12 tasks. The model is implemented and solved using GUROBI solver. As expected, energy consumption is reduced when considered in the objective. When we incorporate the worker factors, the OCRA index is better and the tasks are not allocated in the same way. At this point, we can say that the consideration of these two factors is not negligible. More tests have to be done to confirm this analysis, especially on real data.

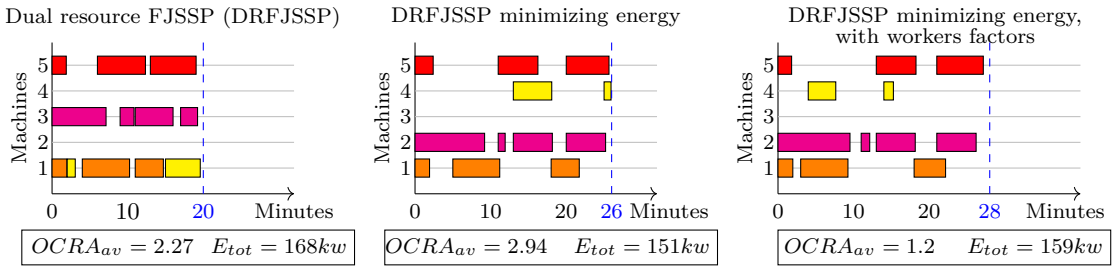


FIG. 3 – Tasks allocation under different FJSSP model.

3 Conclusions and perspectives

We propose a model for the green FJSSP considering human factors. Thereafter, we will implement an approximate solution method to solve larger instances. Furthermore, we want to switch to a multi-objective model considering human factors in the objective function together with environmental concerns. Then, our objective is to move to a dynamic model, through which we can achieve a human-centered, sustainable and resilient approach for the FJSSP.

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